Wireless & Conductive Charging Testing to support Code & Standards

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Energy Storage & Transportation Systems
Advanced Vehicle Testing Activity (AVTA)

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Project ID VSS096

2015 DOE Vehicle Technologies Program Annual Merit Review

INL/MIS-15-34806

www.inl.gov

Idaho National Laboratory

Overview

Timeline

FY14

- Wireless Charger testing, analysis and reporting. Support codes and standards

FY15

- Wireless charging bench and vehicle testing to support test procedure requirements
- Conductive EVSE evaluation, power quality and test procedure support for EPA Energy Star

Barriers

- Lack of common test procedures for wireless charger vehicle testing and wireless charger bench testing
- Compatibility / Interoperability and safety issues and potential cyber security vulnerabilities
- Charging systems power quality impacts on the grid especially at reduced power

Budget

- FY14: $ 600k
- FY15: $ 400k

Partners

- OEMs and Industry partners
  - SAE J2954
  - Evatran LLC
- EPA Energy Star

Objective / Relevance

- Provide unbiased and independent testing for:
  - Wireless charging systems
  - Conductive electric vehicle supply equipment (EVSE)
  - Vehicle On-board charging systems
- Conduct benchmark testing of prototypes, field-deployed, and vehicle-integrated charging systems
- Provide DOE with feedback for technology development investments and FOAs (Funding Opportunity Announcements)
- Provide the charging, automotive, and electric utility industries with independent testing assessments and results
- Support industry's development of wireless and conductive charging standards and test procedures

Milestones

Completed :

- Testing of Evatran's *production* PLUGLESS™ wireless charger
  - as installed on a vehicle
  - bench testing as standalone sub-system
- Compare efficiency and EM field results as impacted by
  - Alignment, gap, and charge power
- Support SAE J2954 (wireless charging) development
  - INL provided specific test setup details for both vehicle and bench test setup
- Drafted conductive EVSE test procedures to support EPA proposed Energy Star rating of EVSE power consumption
- Completed evaluation of four smart grid EVSE for FOA-554
- Published power quality results from one PHEV on-board charge system

Approach:
INL's Electric Vehicle Infrastructure (EVI) Laboratory

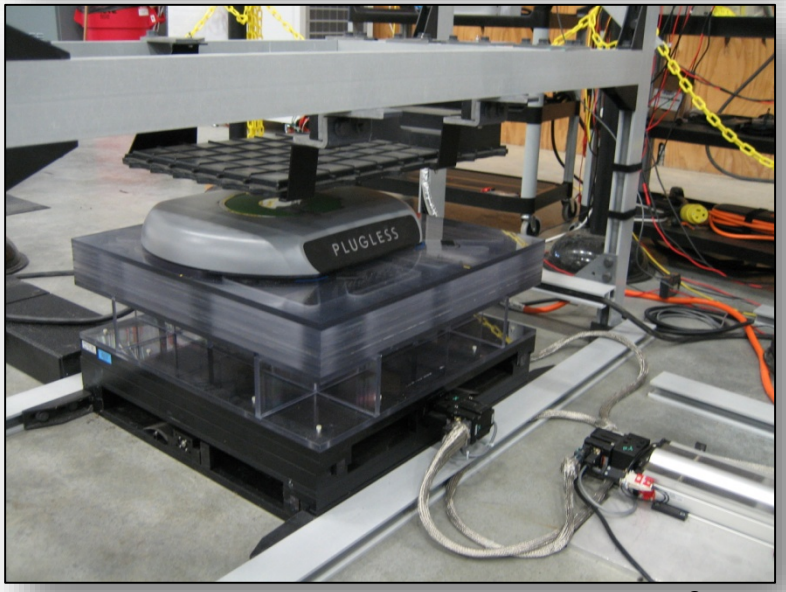
- Evaluate Conductive and Wireless Charging Systems
  - Charging Efficiency and power consumption
  - EM field emissions (wireless charging only)
  - Power Quality (static and dynamic)
    - Total Harmonic Distortion
    - Power Factor
  - Cyber Security Assessment
    - Physical security
    - Communications security
      - wired and wireless
    - Software and firmware
- Wide range of input power
  - Level 1, 120 VAC
  - Level 2, 208 / 240 VAC
  - DCFC, 480 VAC 3ϕ
- Vehicle emulator
- Chevy Volt and Nissan Leaf

Approach:
INL's Wireless Charging Testing and Evaluation

- On-board vehicle testing
  - Integrate and tuned for the vehicle by the WPT manufacturer

- Standalone sub-system testing (bench test)
  - Fiberglass test fixture supports 2nd coil
  - Other equipment to emulate vehicle functions (comm., power transfer)

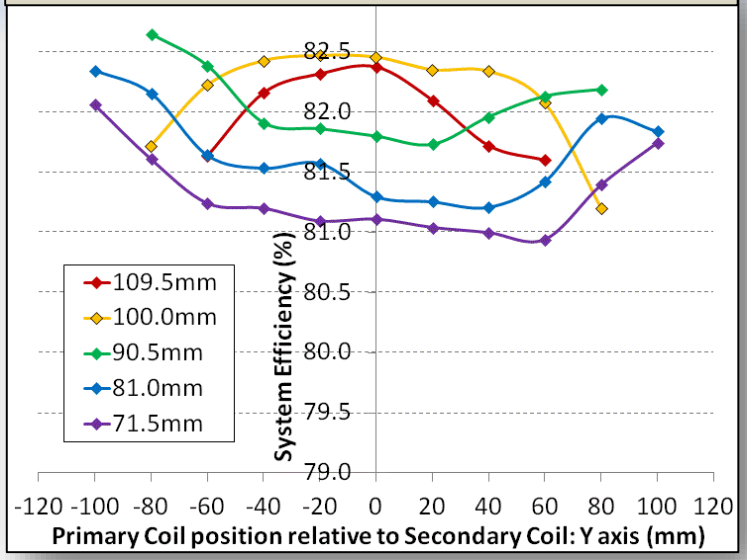
- Multi-axis computer controlled
  - X & Y axis coil alignment to evaluate impact of coil to coil misalignment
  - X & Z axis EM field sensor positioning around the WPT system
  - Manual Z (gap) variation by adding / removing 9.5 mm shims under primary



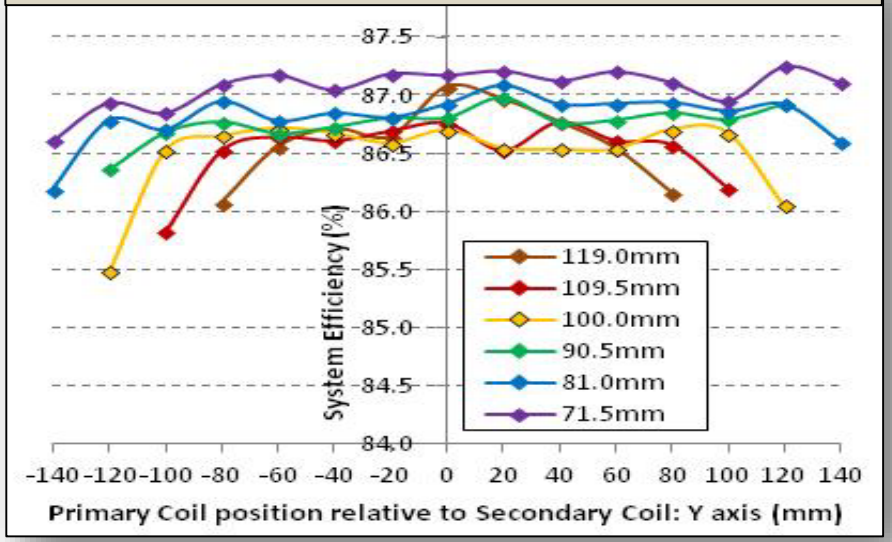
Accomplishments: Comparison of PLUGLESS™ Power Transfer Efficiency

- Comparison of Vehicle and Bench Test Results
  - 4% to 6% efficiency difference
  - 40 mm difference in maximum coil misalignment operating range
  - Variation in efficiency with change in coil gap
  - Coil gap with highest efficiency when coils are aligned
    - Vehicle: 100 mm gap
    - Bench: 71.5 mm gap
  - Difference in efficiency and system performance are due to EM field interaction with the steel vehicle chassis

Vehicle Efficiency (Chevy Volt)



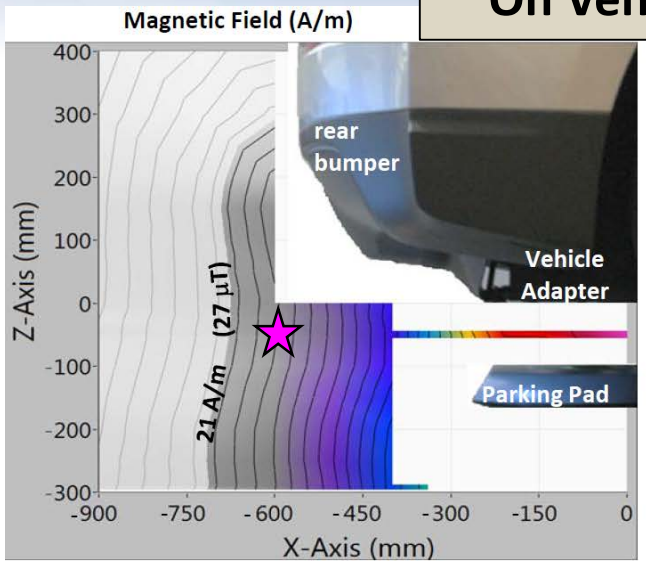
Bench Test Efficiency

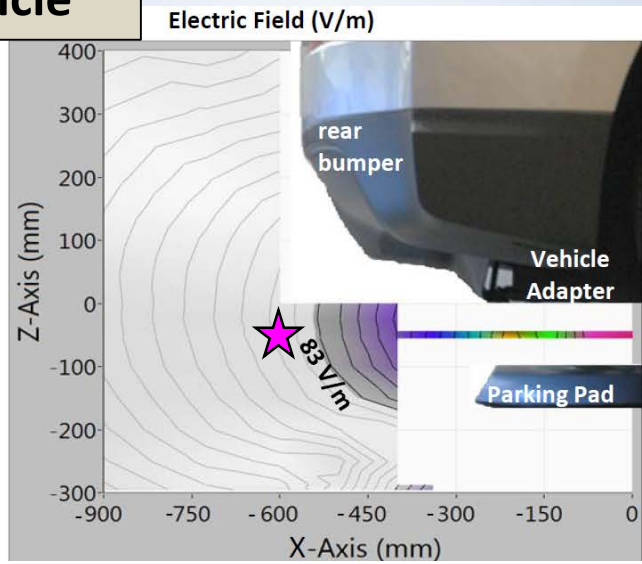


PLUGLESS™ EM-field measurements

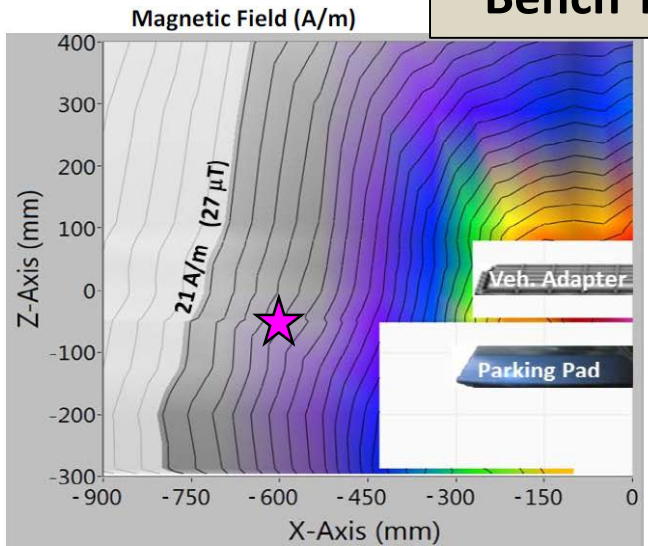
- EM field shape is altered by vehicle chassis
- At rear bumper centered between coils (-600, -50)★
  - Vehicle
    - 42.2 μT
    - 57.3 V/m
  - Bench Test
    - 53.7 μT
    - 101.5 V/m

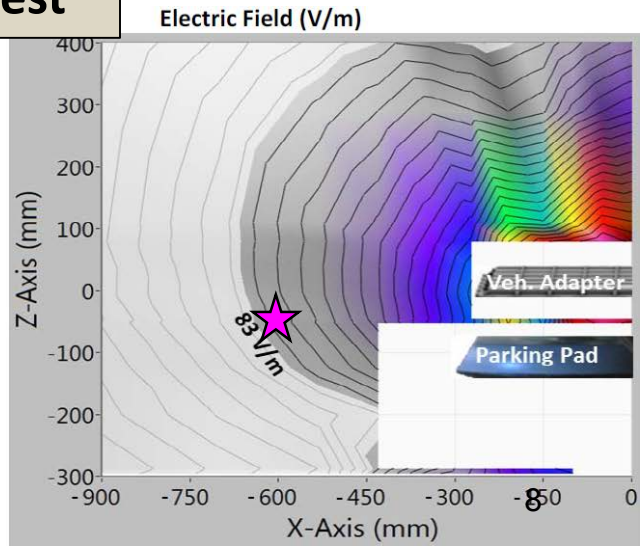
On Vehicle





Bench Test





Fact Sheet: Vehicle Test Results

Idaho National Laboratory

Advanced Vehicle Testing Activity

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Laboratory Testing as installed on a 2012 Chevy Volt

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240	VAC
Circuit Breaker Rating	30	A
Nominal gap between coils	100	mm
Rated maximum power output	3300	watts
Parking Pad (Primary Coil system)		
Shape	Approximately Circular	
Size	559 dia. x 470 long	mm
Vehicle Adapter (Secondary Coil system)		
Shape	Rectangular	
Size	762 long x 457 wide	mm

Measured System Parameters during nominal, steady state conditions [2]

Input Power		
Input Voltage	208	VAC
Input Current RMS	28	Amps RMS
Power Factor	0.60	
Voltage Total Harmonic Distortion (THD)	3	%
Current Total Harmonic Distortion (THD)	134	%
Wireless Power Transfer Operation		
Operating Frequency (kHz)	18 - 20	kHz (variable)
DC Output Power (into On-Board Charge Module)		
Output Voltage	215	VDC
Output Current	13.8	Amps
Output Voltage Ripple Factor	0.76	%
Operating Temperature after 4.0 hours at 3.0 kW output		
Parking Pad: Max observed surface temperature	51	°C
Vehicle Adapter: Max observed surface temperature	48	°C

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp/wp-content/uploads/2014/02/Plugless_Tech_Specs.pdf

[2] Test conducted at nominal conditions (3.0 kW output, 100mm coil gap, coils aligned) unless otherwise specified

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...ESS™ Vehicle Adapter into On-Board Charge Module

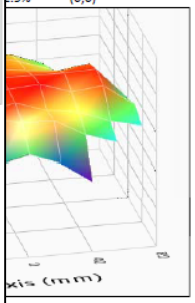
...SS™ Control Panel from 208 VAC

...fully recharged)[2]

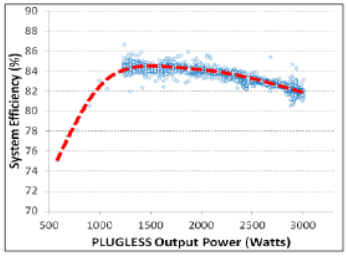
	15.3 kWh
	12.6 kWh
	82.3 %
	4.5 hours

...nt[2] — Primary Coil position relative to Secondary Coil (mm)

2.5%	(20,-20)
2.5%	(0,0)



System Efficiency at Various Output Power[2]



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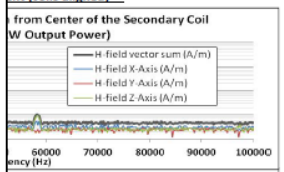
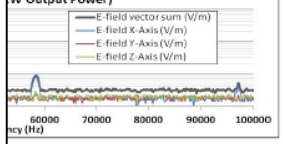
...ent (coils aligned)[2,3]

...from Center of the Secondary Coil ...W Output Power)

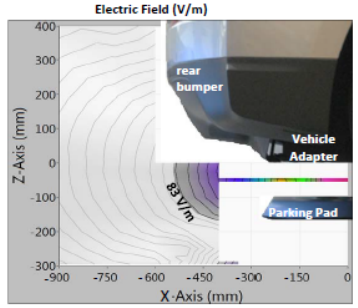


...from Center of the Secondary Coil ...W Output Power)



...mper[2]

Electric Field (V/m)



EM Field meter position (X,Z)

...490 A/m	(1872 µT)	(0,-50) centered between coils
...425 V/m		(0,-50) centered between coils
...33.6 A/m	(42.2 µT)	(-600,-50) at rear bumper
...57.3 V/m		(-600,-50) at rear bumper
0.5 A/m	(0.6 µT)	(0,250) inside trunk above charge system
0.8 V/m		(0,250) inside trunk above charge system

...w secondary coil) 0.8m from Secondary Coil Center along X-axis

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...Watts

...0.0 µT)

EM Field measurement position
top surface center of parking pad
top surface center of parking pad

...00mm coil misalignment)

...Watts
...econds

...847 µT)

EM Field measurement position
top surface center of parking pad
top surface center of parking pad

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http://avt.inel.gov/evse.shtml

Fact Sheet:
Bench Test Results (standalone)

Idaho National Laboratory

Advanced Vehicle Testing Activity

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Laboratory Testing off-board the vehicle

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240 VAC
Circuit Breaker Rating	30 A
Nominal gap between coils	100 mm
Rated maximum power output	3300 watts
Parking Pad (Primary Coil system)	
Shape	Approximately Circular
Size	559 dia. x 470 long mm
Vehicle Adapter (Secondary Coil system)	
Shape	Rectangular
Size	762 long x 457 wide mm

Measured System Parameters during nominal, steady state conditions [2]

Input Power	
Input Voltage	208 VAC
Input Current RMS	28 Amps RMS
Power Factor	0.60
Voltage Total Harmonic Distortion (THD)	3 %
Current Total Harmonic Distortion (THD)	132 %
Wireless Power Transfer Operation	
Operating Frequency (kHz)	18 - 20 kHz (variable)
DC Output Power (into programmable DC electronic load)	
Output Voltage	215 VDC
Output Current	13.9 Amps
Output Voltage Ripple Factor	0.75 %
Operating Temperature	
Parking Pad: Max observed surface temperature	51 °C
Vehicle Adapter: Max observed surface temperature	48 °C

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp/wp-content/uploads/2014/02/Plugless_Tech_Specs.pdf
[2] Test conducted at nominal conditions (3.0 kW output, 100mm coil gap, coils aligned) unless otherwise specifie

ncy

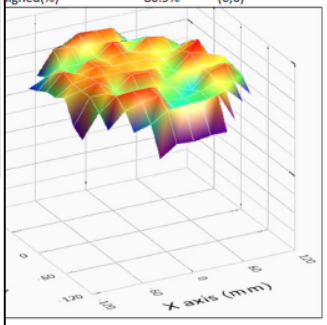
arging System Efficiency

Energy out of PLUGLESS™ Vehicle Adapter into programmable DC Load
Energy into PLUGLESS™ Control Panel from 208 VAC

tion with coil misalignment[2]

ncy (%)	87.3%	(80,20)
ligned(%)	86.9%	(0,0)

Primary Coil position relative to Secondary Coil (mm)



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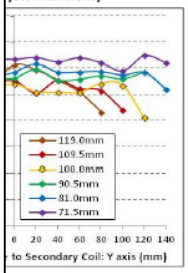

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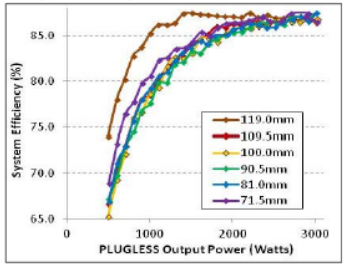
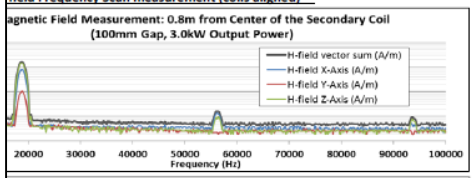
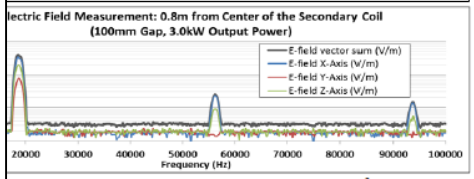


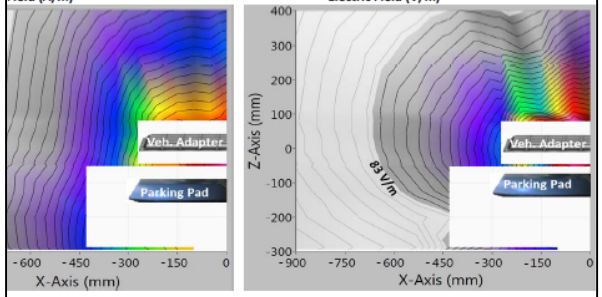
ic and Electric Field

field Frequency Scan measurement (coils aligned)[2,3]





& Electric fields around the rear side of the PLUGLESS system[2]



rements[2]

measured H-field	1587 A/m (1994 µT)	(0,-50)	between coil centers
measured E-field	6833 V/m	(-50,80)	above the vehicle adapter
m from coil center	42.7 A/m (53.7 µT)	(-600,-50)	at rear of system
m from coil center	101.5 V/m	(-600,-50)	at rear of system

EM Field meter position (X,Z)

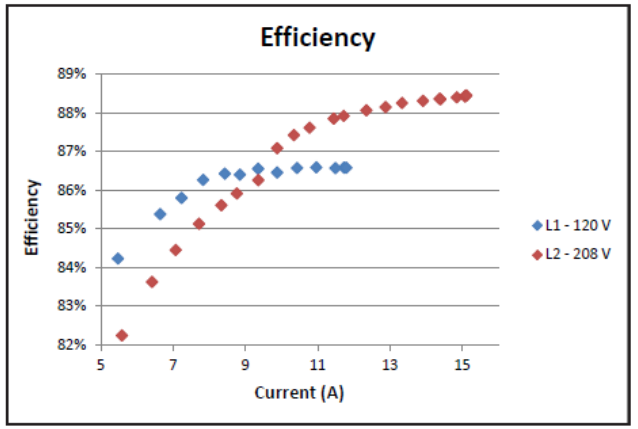
[3] EM field measurement is centered between the gap (50mm below secondary coil) 0.8m from Secondary Coil Center along X-axis

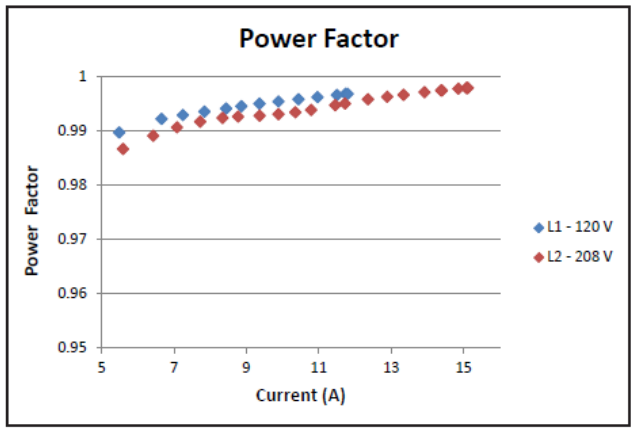
http://avt.inel.gov/evse.shtml

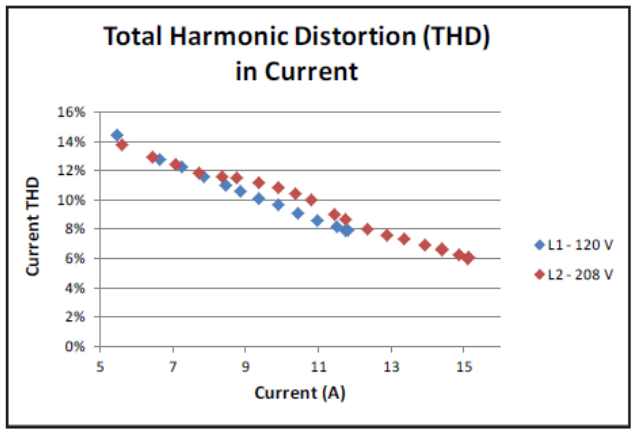
Accomplishments: Charger Power Quality

- Power Quality of On-Board Charge Module evaluated in accordance to SAE J2894
  - Level 1 and Level 2
    - Efficiency
    - Power Factor
    - Total Harmonic Distortion
- Power Quality decreases as charge current decreases (undesirable impact to grid)
  - Efficiency decreases
  - Power Factor decreases
  - Distortion on Current increases
- Figures on right are results from
  - 2012 Chevy Volt

http://avt.inel.gov/pdf/EREV/SteadyStateVehicleChargingFactSheet2012Volt.pdf







Accomplishments: Conductive EVSE test procedures for Energy Star

- Draft document created for Level 1 and Level 2 EVSE testing
  - Definitions
  - Test equipment requirements
  - Test procedures
    - Standby power consumption
    - Power consumption during charging
- Recommendations of consideration additional features that may impact EVSE power consumption
  - EVSE rated maximum current
  - Cord length
  - Additional features:
    - Status lights, communication, touch screen, # of cords, etc.

Accomplishments: Evaluation of 4 Smart Grid Capable EVSE

- Four smart grid capable EVSE evaluated
  - As part of the U.S. DOE FOA-554
    - Four awardees developed EVSE with smart grid communication capabilities
      - GE, Eaton, Delta, Siemens
  - Final deliverable EVSE were evaluated by INL
    - Operational and efficiency testing
      - Power consumption during charging and standby
      - Operational functionality
    - Cyber Security Vulnerability assessment
      - Physical security
      - Communications security (wired and wireless)
      - Software and firmware assessment
  - INL test results
    - Fact Sheet published to AVTA website
    - Report provided to NETL (contract manager)

Response to Previous Year Reviewer Comments

- Reviewer stated: “The reviewer commented that, instead of writing generalities, they would like to see a more strategic approach as to what INL would like to test including identifying where there are "holes" in the SAE procedures and standards, and suggesting a way to plug the holes. .”
- INL provided specific test fixture and test setup language for the J2954 document. It detailed equipment requirements for coil alignment setup as well as harmonized setup between bench testing and vehicle testing.

- Reviewer stated: “…what else the researchers can do with their resources. The commenter also asked how far INL can push on this. The reviewer concluded by stating that this looks like a great start. ”
- In addition to increased support of SAE J2954 test procedures for both bench testing and vehicle testing, INL is supporting EPA Energy Star by developing and validating conductive EVSE test procedures. Additional efforts are also expanding to test power quality of charging system by the methods in accordance to SAE J2894.

Future Work

- Conduct testing of two wireless charging systems from the awardees of the FOA-667 at the beginning of Phase III
- Obtain and test other wireless charging systems in an effort to benchmark technology and refine test procedures
- Continue to support SAE J2954 test procedure and standards development
  - Support wireless charging interoperability test procedure development
    - Conduct testing to validate interoperability testing methods and procedures
- Evaluate power quality of on-board charger of Nissan Leaf 3.3 kW (2012) and 6.6 kW (2015)
- Complete conductive EVSE power consumption test procedures to support EPA Energy Star

Summary / Comments:

- Completed: INL's laboratory testing of the production PLUGLESS™ Wireless Charging system by Evatran Group Inc.
  - Fact Sheet published (bench test and vehicle test)
    - **http://avt.inel.gov/evse.shtml**
  - Reinforced importance of both forms of testing (bench & vehicle)
- INL provided specific test setup details for both vehicle and bench test setup to SAE J2954 wireless charging document
- Power quality evaluation of the on-board charge system published of one PHEV
- Evaluation complete: four smart gird EVSE for the FOA-554
- Draft test procedures for conductive EVSE power consumption were provided to EPA Energy Star

Acknowledgement

This work is supported by the U.S. Department of Energy's EERE Vehicle Technologies Office

More Information

http://avt.inl.gov